Solar energy – new photovoltaic technologies

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Solar Energy – New Photovoltaic Technologies

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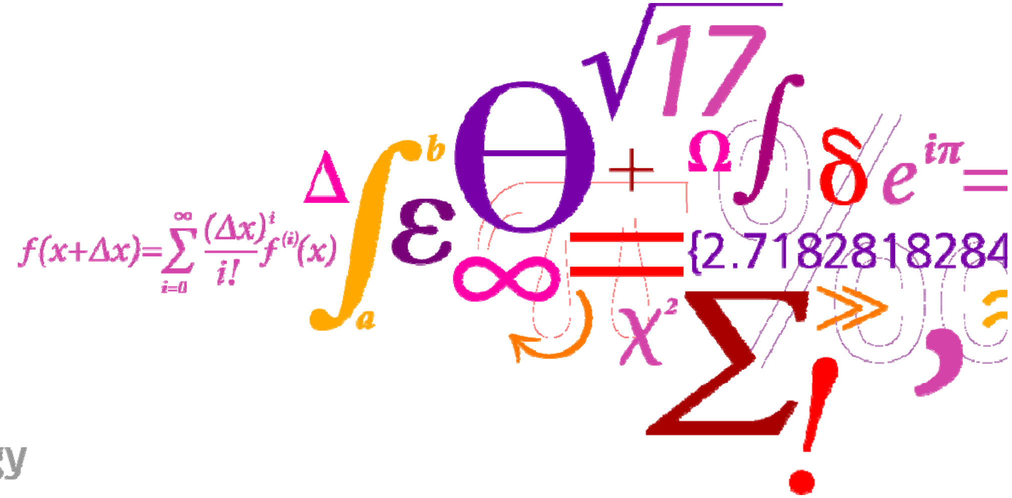


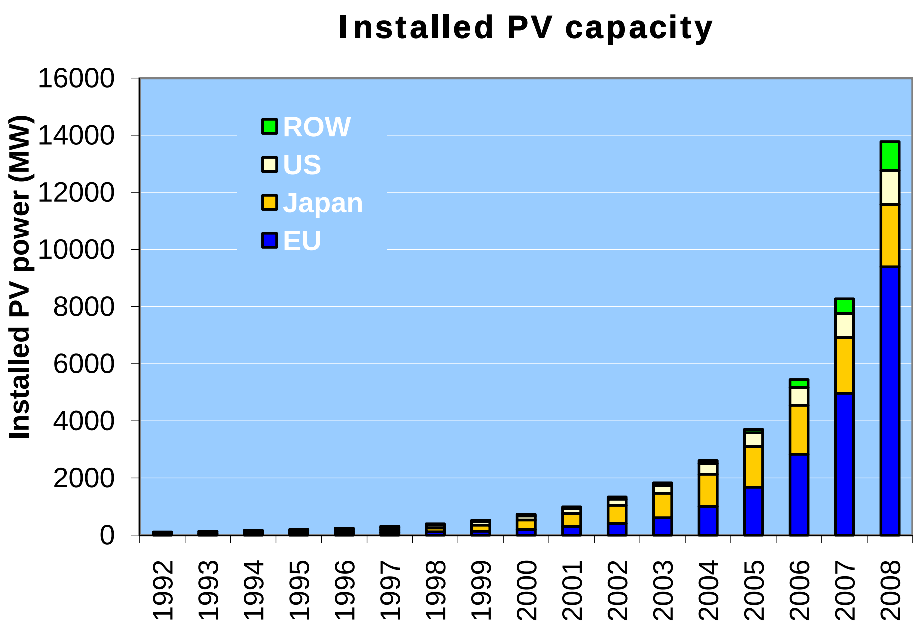
Risø DTU
National Laboratory for Sustainable Energy

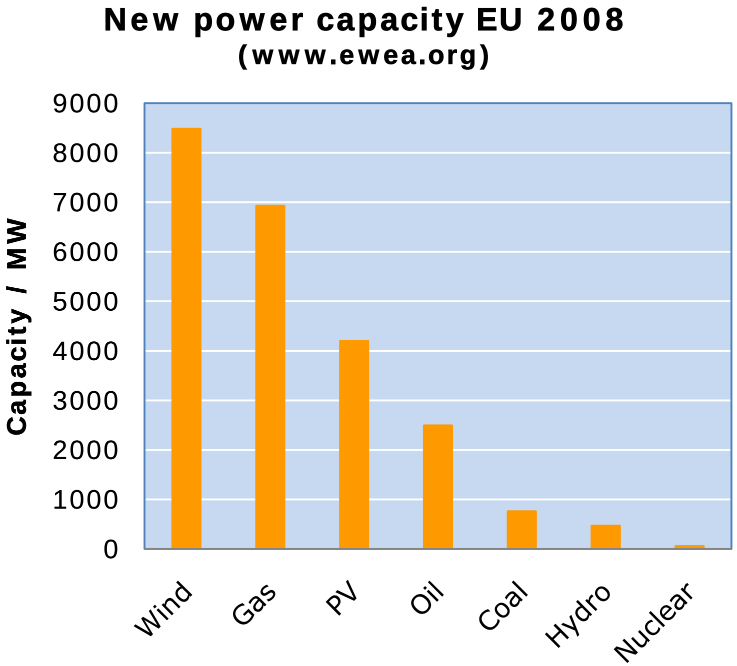
Photovoltaics

- Brief PV status
- New technologies in the pipeline
  - Thin film
  - Polymer solar cells
- Net energy production during deployment

Photovoltaics – the promises

- SOLAR EUROPE INDUSTRY INITIATIVE (SEII), EPIA 2009
- *Reaching a PV contribution to the overall EU electricity demand of 4% in 2016 and 12% in 2020, 20% in 2030 with a potential of up to 50% in 2050.*
- *Typical turn-key large system price of 2 €/Wp by 2015 and <1.5 €/Wp by 2020 PV electricity generation cost in Southern EU of 0.13 €/kWh in 2015 (below retail electricity prices = grid parity) and below 0.06 €/kWh by 2030 (below wholesale electricity prices). Grid parity in most of EU by 2020.*





PV electricity prices

•Map of Solar radiation – from wikipedia: (http://en.wikipedia.org/wiki/File:EU-Glob_opta_presentation.png)

•Table of electricity prices ($/kWh) versus solar cell price ($/Wp) at different insolations (kWh/kWp/year) – from Wikipedia:

(http://en.wikipedia.org/wiki/Photovoltaics)

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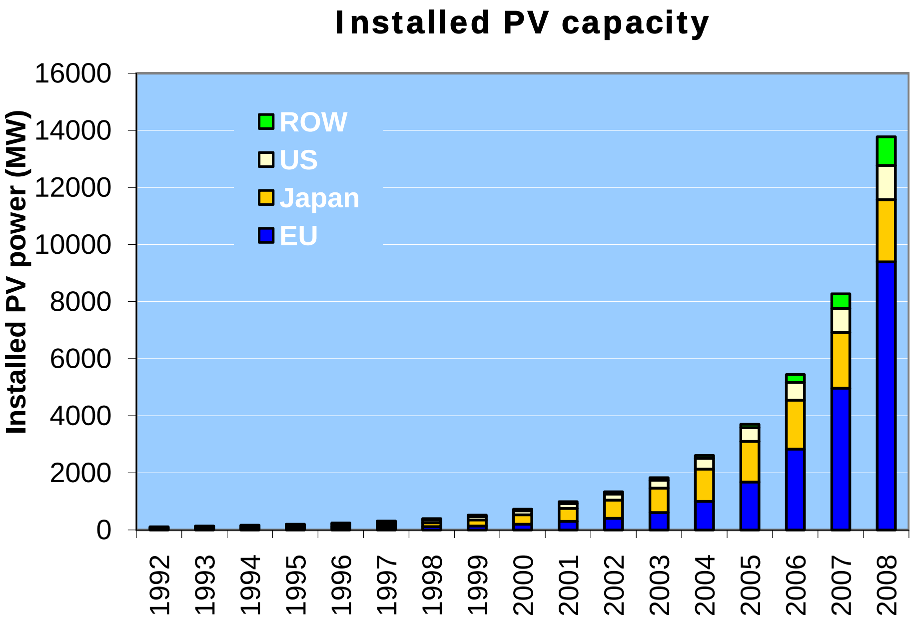
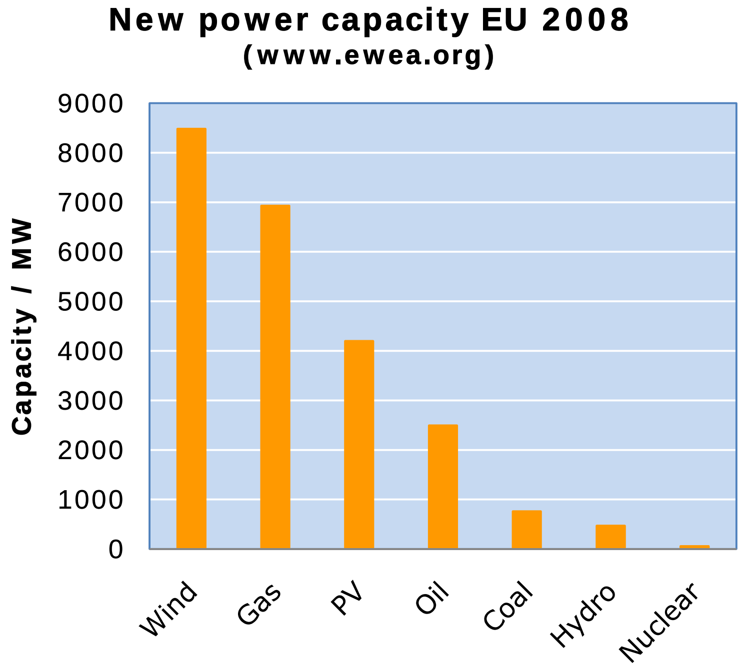
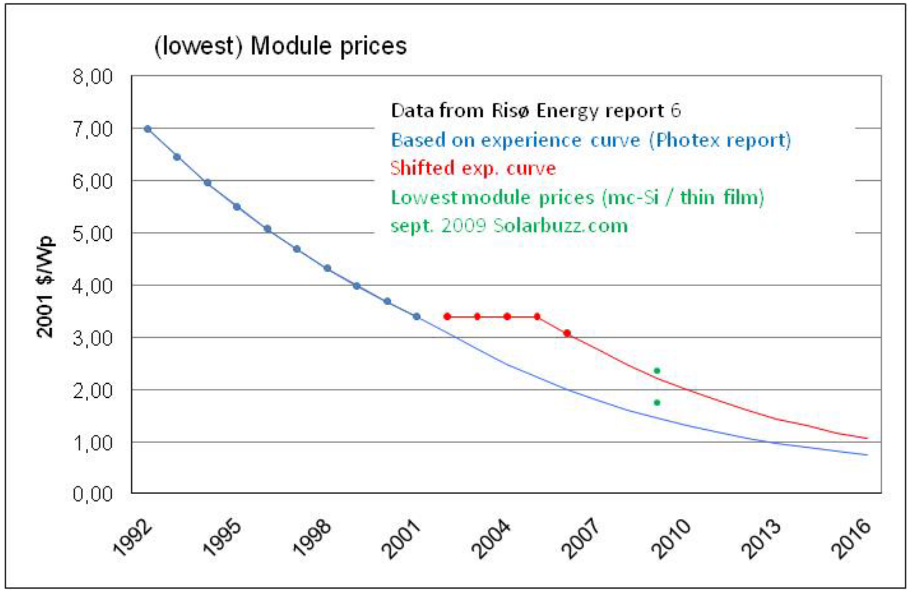
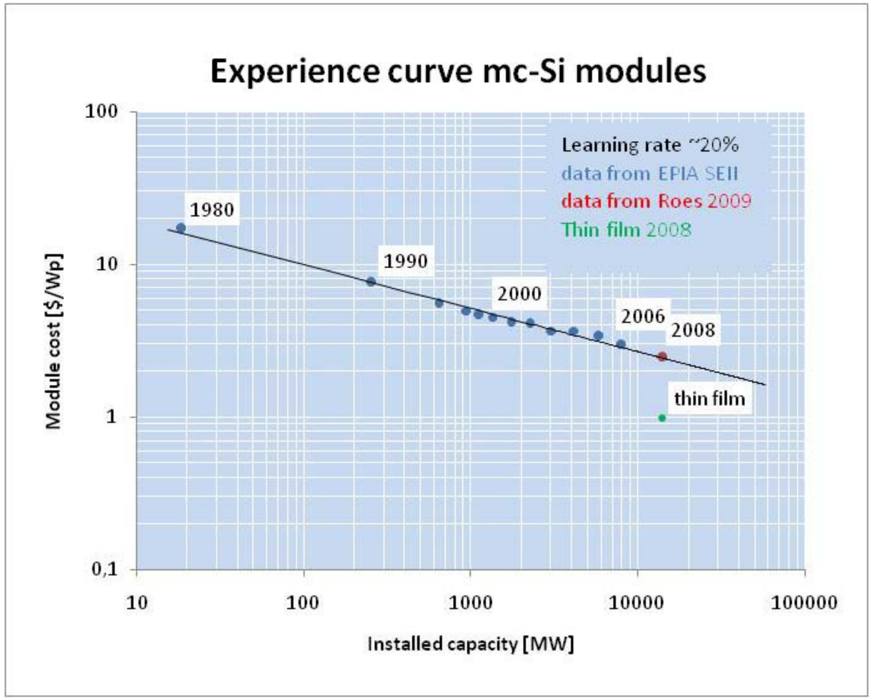




Learning curve / price curve

- Production capacity:
  - 6.9 GW (2008, Solarbuzz)
  - 15 GW (2009, EPIA) -> 35 GW (2013, EPIA *Global market outlook for photovoltaics until 2013*)





Photovoltaics - status

- 34th version of *Solar Cell Efficiency Tables* (Green, M.A., Emery, K., Hishikawa, Y., Warta, W., 2009, (Version 34), Prog. Photovolt: Res. Appl., 17:320–326)
- Efficiencies measured at STC (standard test conditions): 25 deg. C, 1000 W/m^2, AM1.5G solar spectrum.

Technology	Cell	Module	comment
	1st generation		
Mono c-Si	25.0%	22.9%	
Multi c-Si	20.4%	15.5%	
Mono c-GaAs	26.1%		
	2nd generation		
Amorphous Si	9.5%	10.4%	Module is a-Si/a-SiGe/a-SiGe (tandem)
CIGS	19.4%	13.4%	Sputtered/CVD
CIGS printed	16.4%	11.3%	According to Nanosolar
CdTe	16.7%	10.9%	
	3rd generation		
Dye sensitized	11.2%	8.4%	
Dye sensitized flex		3-6%	According to G24i
Organic Polymer	6.4%	1-2%	
	High efficiency		
GaInP/GaAs/Ge	32.0%		Multijunction
GaInP/GaInAs/Ge	41.2%		Multijunction, concentrator (454 suns)
Mono c-Si	27.6%		Concentrator (92 suns)

Photovoltaics - New technologies

- Printed CIGS ink ($CuIn_xGa_{1-x}Se_2$)
  panel production cost estimate:
  0.99 $/Wp (Nanosolar, Inc.)
  640 MWp/y production capacity
- CdTe thin film
  production cost estimate:
  0.98 $/Wp (First Solar, Inc.)
  ~1000 MWp production capacity

- PICTURES FROM www.nanosolar.com: *Ultra-Low Cost Solar Cells: An Overview of Nanosolar's Cell Technology Platform* (in pdf format), Nanosolar White Paper, September 2009

Materials abundance and costs

- [Wadia C , Alivisatos AP, Kammen DM, *Materials Availability Expands the Opportunity for Large-Scale Photovoltaics Deployment*, Environ. Sci. Technol., 2009, 43 (6), pp 2072–2077]
- Annual electricity potential index (from known economical reserves)
- Materials extraction cost index (from minimum cost/Wp)

PV technology	Ann. Elec. Pot. index	Mat. Extrac. Cost index
mc-Si	1	1
a-Si	$5 \cdot 10^{5}$	$5 \cdot 10^{-6}$
CdTe	10^{-7}	3
CIGS	10^{-2}	0.6

Indium: Reserve 2.800 Tons, global production 500 tons/y
Cd: Reserve 540.000 tons, global production 20.900 tons/y
Ag: Reserve 270.000 tons, global production 19.500 tons/y
[U.S. Geological Survey, *MINERAL COMMODITY SUMMARIES 2007*]

Life cycle analysis and energy payback time

- Full lifecycle analysis is not available
  [Roes AL,Alsema EA, Blok K, Patel MK, *Ex-ante Environmental and Economic Evaluation of Polymer Photovoltaics*, Prog. Photovolt: Res. Appl. 2009; 17:372–393]
- NREU: non-renewable energy use
  (production, balance-of-system, installation)
- Energy payback time:
  time to production equals all accounted energy use in LCA

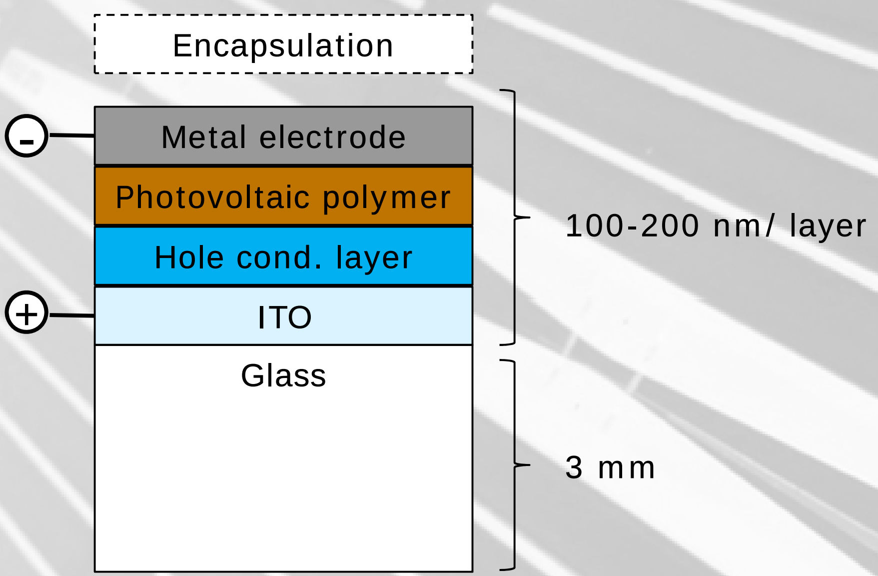
PV-technology	NREU (MJ/Wp)		Energy payback time	
mc-Si	29.8[2]	24.9[3]	2.33	1.95
CdTe	15.7	9.5	1.23	0.75
CIS[1]	40.3	34.6	3.16	2.71
a-Si	24.6	17.1	1.93	1.34
DSSC	11.7	5.8	0.92	0.45
OPV on glass	16.1		1.26	
OPV on PET		2.4		0.19

[1] non-printed

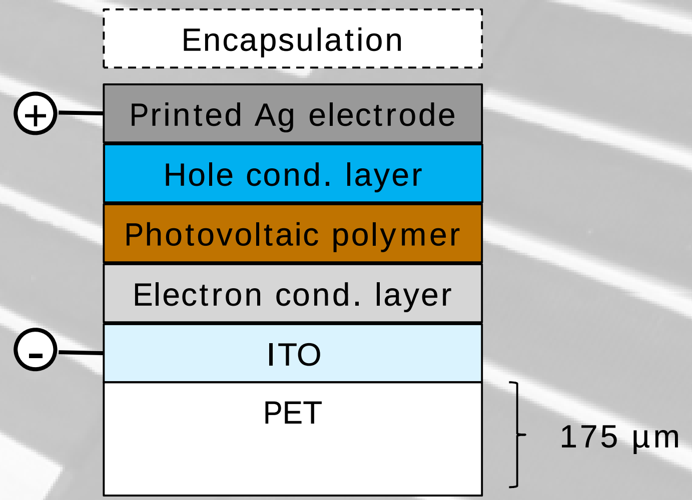
[2] +frame +BOS
[3] -frame -BOS

Polymer Solar Cells

- Schematics of a polymer solar cell



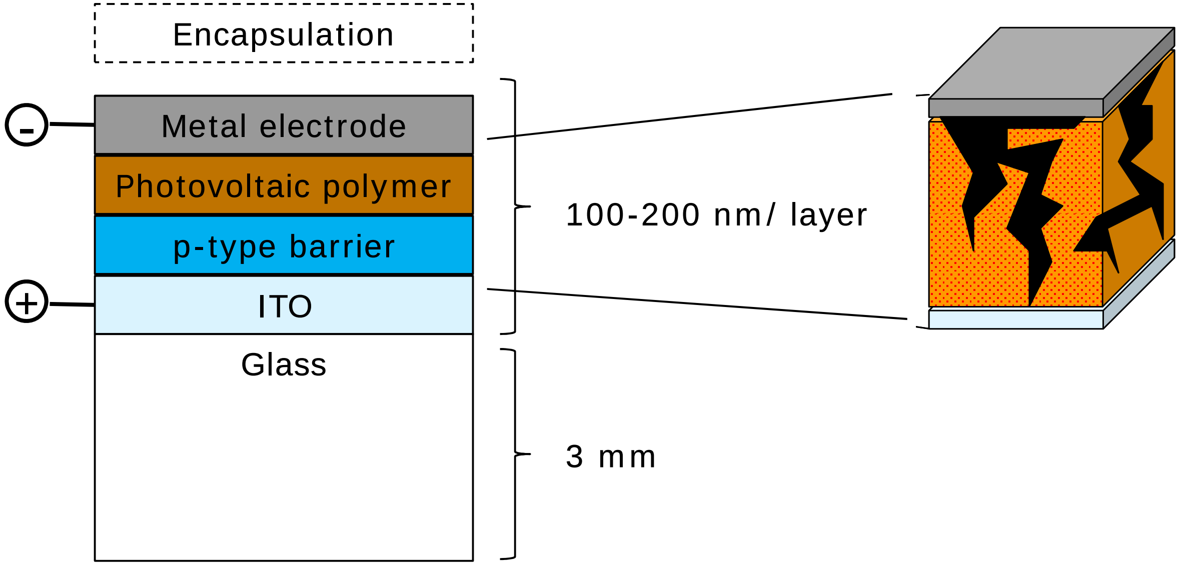
OPV on glass



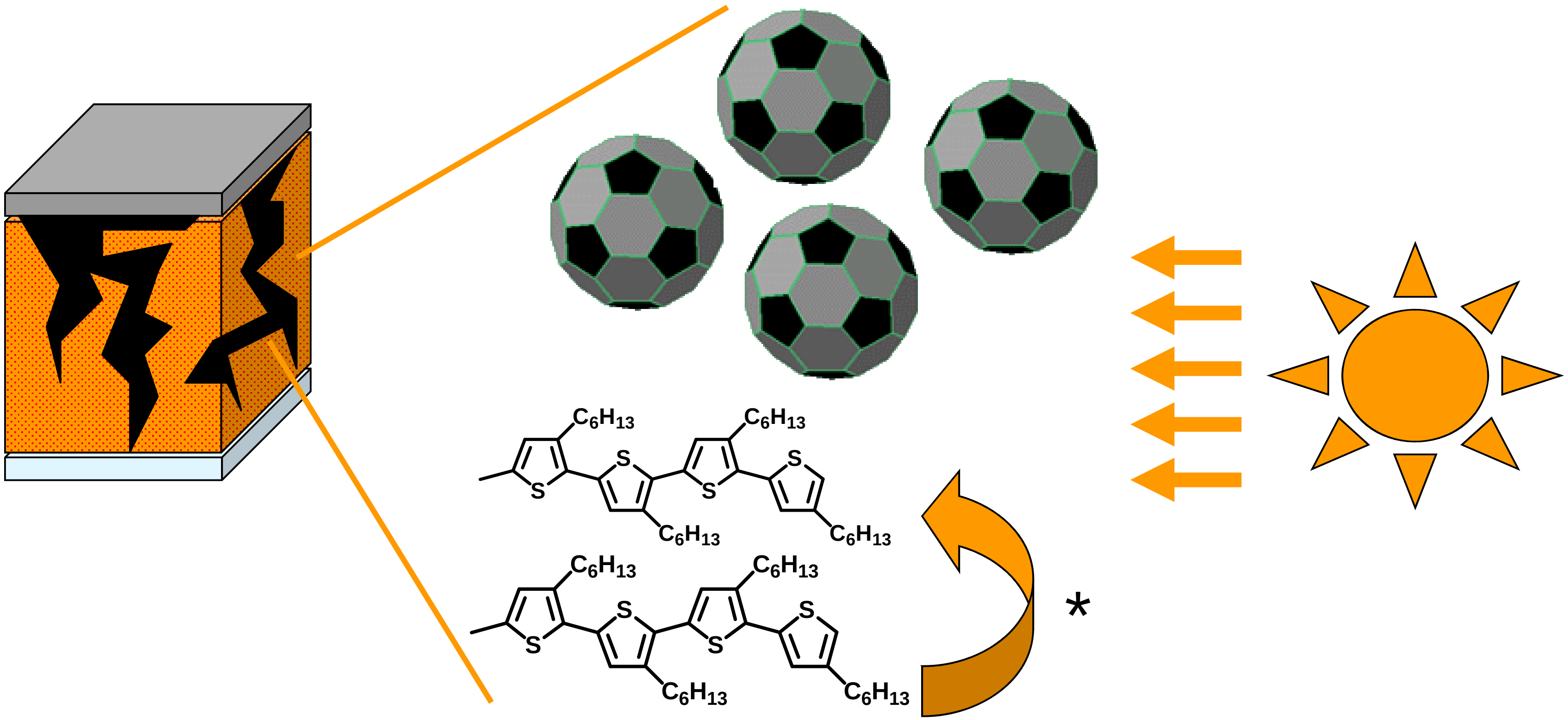
OPV printed on flex substrate

Polymer solar cell

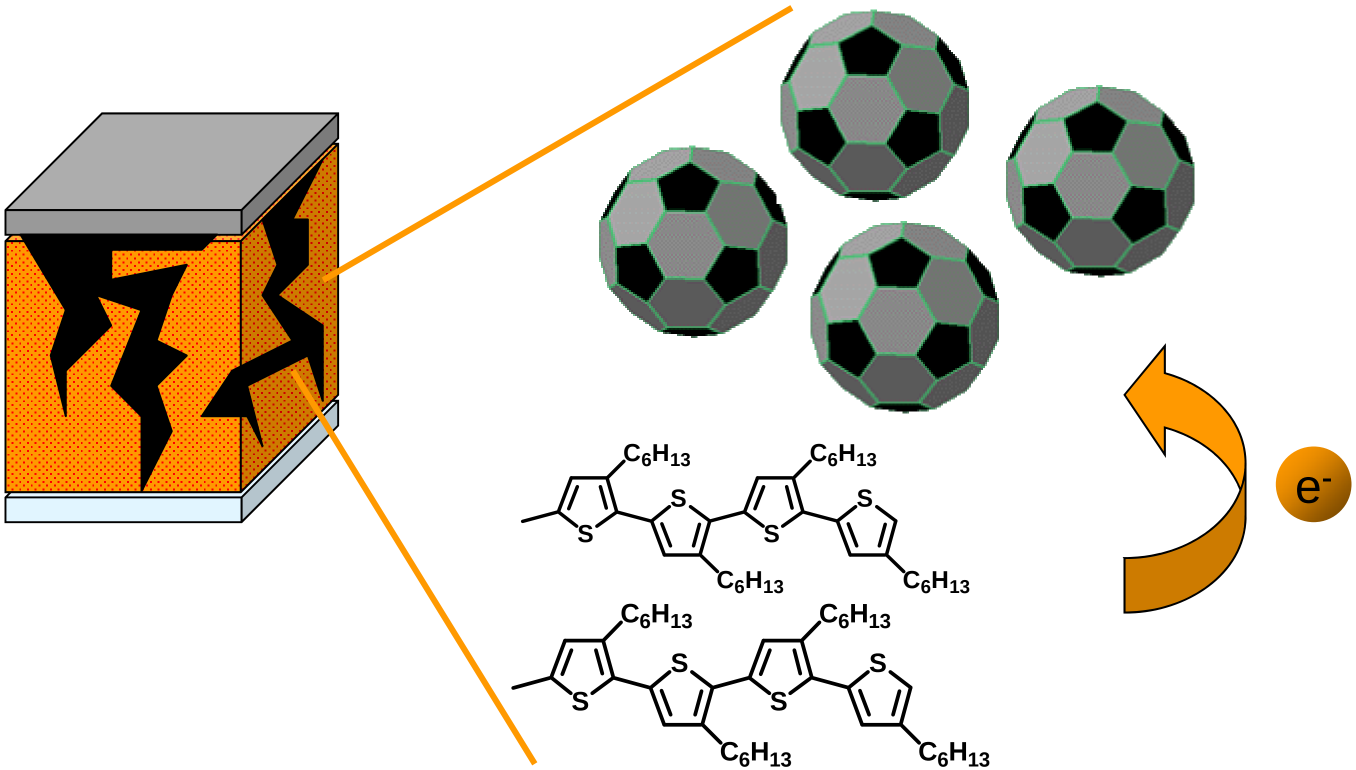
- Yu, G., Gao, J., Hummelen, J.C., Wudl, F., Heeger, A.J., 1995, Polymer photovoltaic cells - enhanced efficiencies via a Network if internal donor-acceptor heterojunctions , Science, 270(5243): 1789-1791
- Bulk hetero junction:



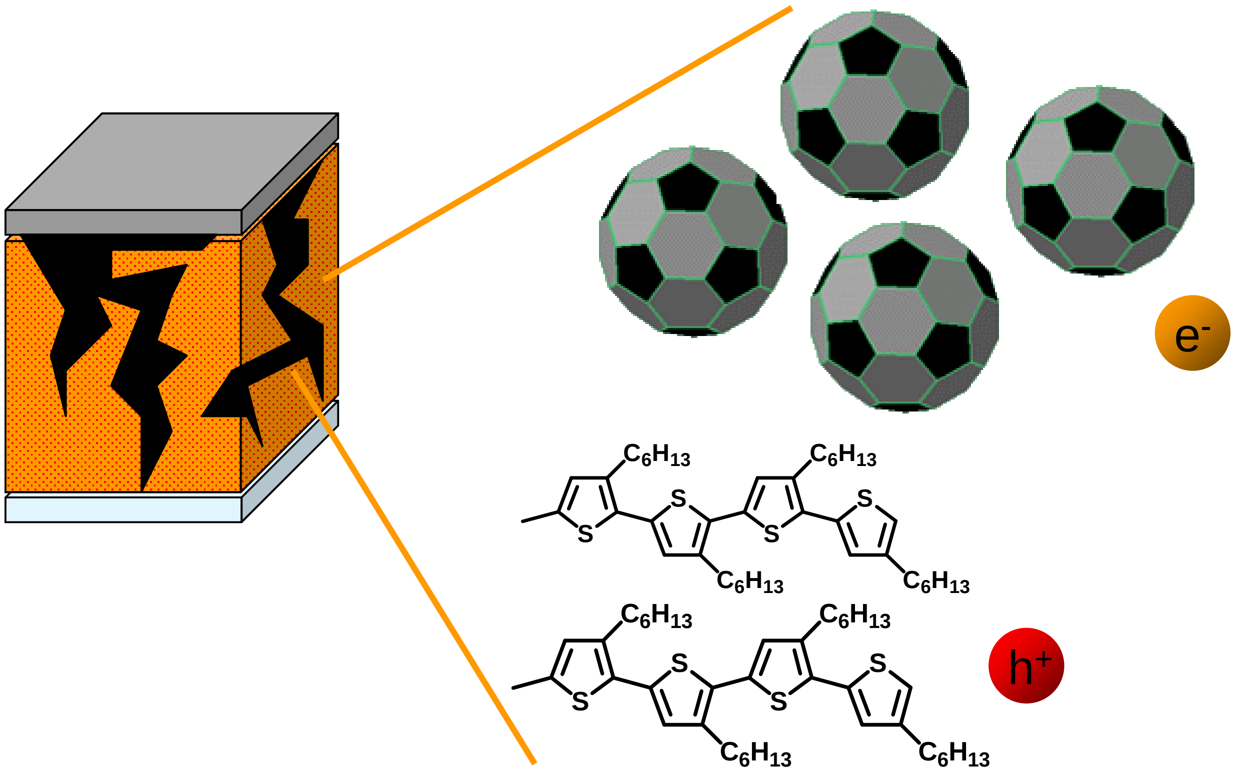
How it works – absorption of light



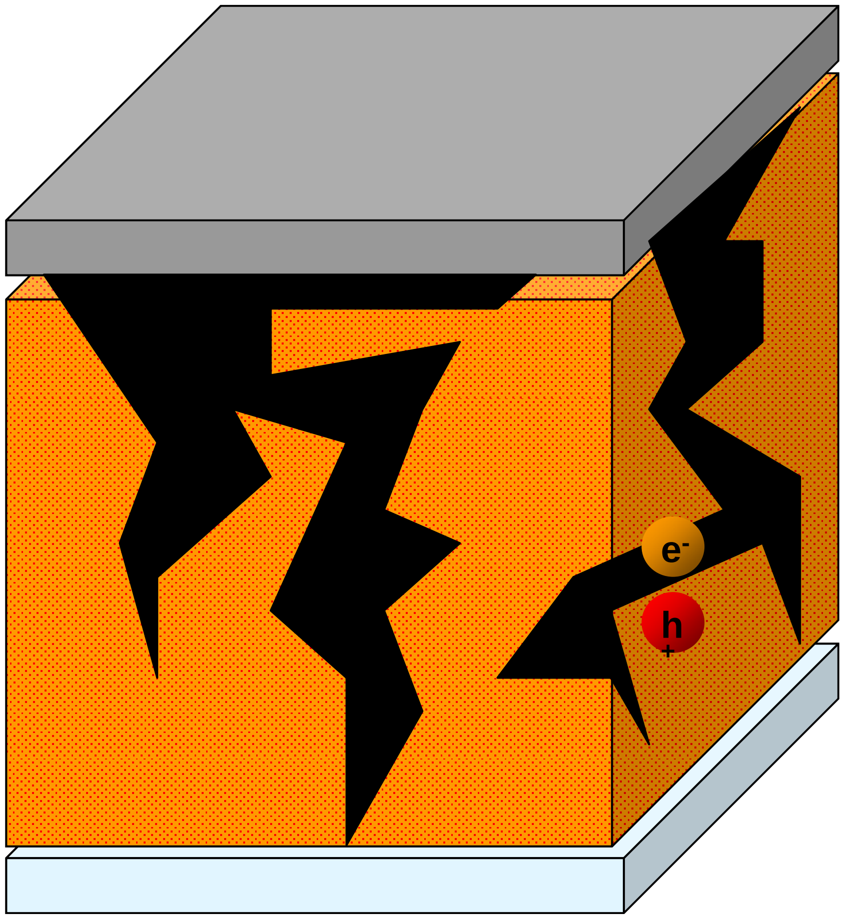
How it works – electron transfer from donor to acceptor



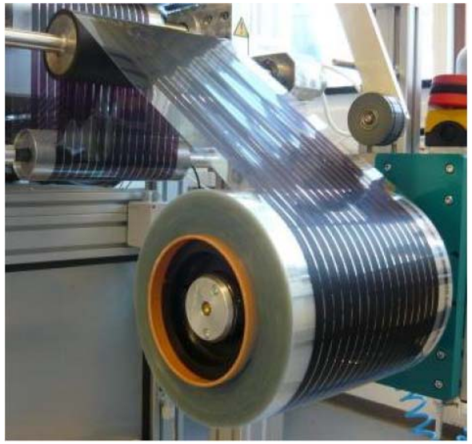
How it works – generation of charge carriers

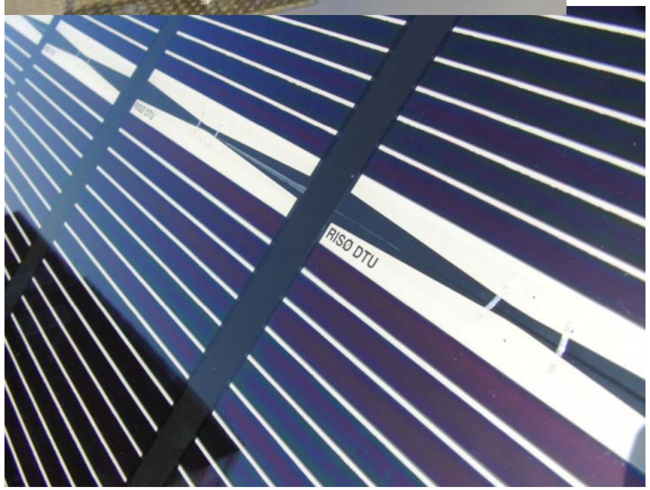


How it works – charge carrier diffusion



Polymer Solar Cells



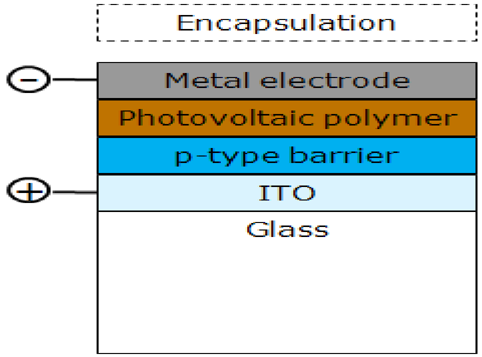


Cold laminated PET with acrylic resin (25 µm)
Ag-paste (6 µm)
PEDOT:PSS (250 nm)
P3CT/PCBM/ZnO or P3CT/ZnO (90 nm)
ZnO (30 nm)
ITO (80 nm)
PET (175 µm)

~ 210 µm

Polymer Solar Cell

- Multiple printing and coating technologies possible
  slot-die coating / screen print (current proces)
- Relatively in-expensive machinery and existing industry segment (printing industry, petrochemical industry)
- Machinery:
  - 1-2 M€ of Coating and screen printing machinery produces
    10 MWp modules/year (1 m^2/minute; 20Wp/m^2;24/7 operation)
- Price: The potential for ultra-low cost
  P3HT/PCBM 40$/g
  Plexcore® 1140€/25 ml (Sigma Aldrich)



Costs of polymer PV on glass and silicon PV (Roes et al. 2009)

Material/process Costs	($/Wp)
ITO coated glass	0.222
PEDOT:PSS	0.000
P3HT/PCBM	0.089
Aluminum	0.000
Module assembly	2.457
BOS	1.375
Evaporation	0.029
polymer PV system	4.178
mc-silicon PV system BOS	3.435 0.935

Polymer solar cell

- First cost study

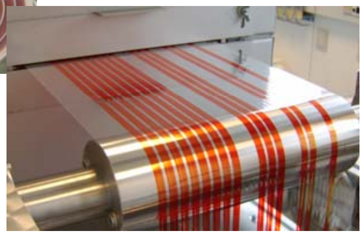
  [Krebs FC, Jorgensen M, Norrman K, Hagemann O, Alstrup J, Nielsen TD, Fyenbo J, Larsen K, Kristensen J, *A complete process for production of flexible large area polymer solar cells entirely using screen printing-First public demonstration*, SOLAR ENERGY MATERIALS AND SOLAR CELLS 93:4, 422-441, 2009]

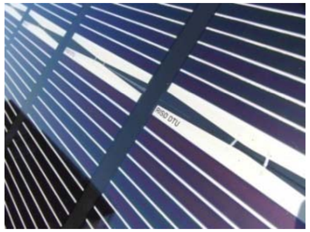
Cost per module / €
(75 cm² active area / 133 cm² total area)

Material	Process costs	Materials costs	Total
PET-ITO	0.287	1.03	1.317
ZnO layer	0.056	0.64	0.696
P3MHOCT/PCBM/ZnO	0.056	1.01	1.066
PEDOT:PSS	0.056	0.15	0.206
Ag paste	0.056	0.32	0.376
Lamination	0.056	0.073	0.129
Laser cutting	0.339		0.339
Crimping contacts	0.636	0.053	0.689
Total	1.542	3.276	4.818

Polymer Solar Cell

- Ultra-low price?





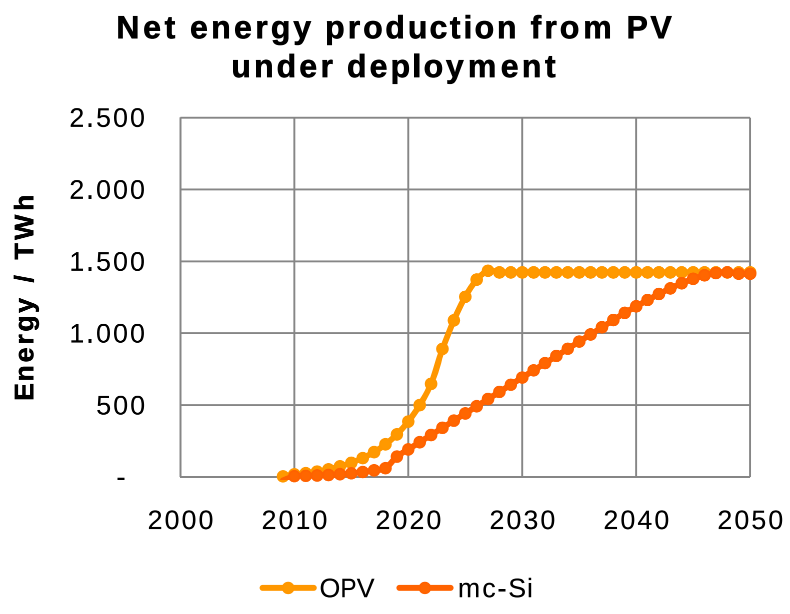
June 2008	January 2009	March 2009	Ultimo 2009
4.500€/W	22€/W	15€/W	4-5€/W

Main drivers: Increased research effort, experience in roll to roll manufacturing, knowhow buildup and cheaper materials.

Net energy production under deployment

- Energy payback time and lifetime are critical parameters for estimating the net energy production under large scale deployment.
- Installations grow exponentially until “production capacity target” has been reached. Afterwards this amount is installed each year.

	OPV	mc-Si
Installation rate	40%	33%
Energy payback time	0,5 y	2 y
lifetime	5 y	30 y
insolation	1250 kWh/kWp/y	
Prod. Capacity	250 GWp/y	50 GWp/y
Capacity (equil.)	1264 GWp	1514 GWp
Energy (equil.)	1424 TWh	1414 TWh



Conclusion

- New photovoltaic technologies like polymer Solar Cells may become more attractive than mc-Si technology because of:
  - Low energy payback time
  - Versatile production environments and low investment costs
  - Low price
  - Abundance of materials (except Ag)
- Major competitors are thin film photovoltaics on the short time scale
  - Low abundance of materials
  - Cd has high environmental and health impact – ROHS directive
- Low energy payback time technologies allow for CO_2-savings also during large scale deployment period.

- Polymer photovoltaics are ready for use in small electronic products. Improvements in efficiency and lifetime and identification of low BOS cost solutions are needed before energy production becomes reality.

Acknowledgement Risø DTU Solar Cell Group

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